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JHRP-ISHD COOPERATIVE STUDY USING KNEADING COMPACTOR AND HVEEM STABILOMETER

APRIL 1961
NO. 9

by

N.G. GAUDETTE, JR.
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Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

JHRP-ISHD COOPERATIVE STUDY USING KNEADING COMPACTOR
AND HVEEM STABILOMETER

TO:	K. B. Woods, Director Joint Highway Research Project	April 6, 1961
FROM:	H. L. Michael, Assistant Director Joint Highway Research Project	File: 2-4-18 Project: C-36-6R

Attached is a report titled, "JHRP-ISHD Cooperative Study Using Kneading Compactor and Hveem Stabilometer". The report has been authored by N. G. Gaudette and W. H. Goetz of our staff. It is transmitted to Mr. Havey for use in his department. It is an example of the cooperation which exists between the Project Laboratories and the State Highway Department.

The report is presented to the Board for the record.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Secretary

HLM:kmc

Attachment

cc: F. L. Ashbaucher
J. R. Cooper
W. L. Dolch
W. H. Goetz
F. F. Havey
F. S. Hill
G. A. Leonards
G. A. Hawkins (M. B. Scott)
J. F. McLaughlin
R. D. Miles
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C. E. Vogelgesang
J. L. Waling
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Final Report

JHRP-ISHD COOPERATIVE STUDY
USING
KNEADING COMPACTOR AND HVEEM STABILOMETER

by

N. G. Gaudette, Graduate Assistant
and
W. H. Goetz, Research Engineer

Joint Highway Research Project
Project No.: C-36-6R
File No.: 2-4-18

Purdue University
Lafayette, Indiana

April 6, 1961

April 4, 1961

File: 2-4-18

Mr. F. F. Havey
Engineer of Materials and Tests
State Highway Department of Indiana
Indianapolis 9, Indiana

Dear Mr. Havey:

Enclosed is a final report of the cooperative kneading compactor and Hveem Stabilometer work done between the Indiana State Highway Department and Joint Highway Research Project bituminous laboratories.

In order to make your data records complete, test results for the final phase of the Purdue work are presented in the first section. The following sections present comparisons of the results obtained in the two laboratories for the final phase of the program in which a type B surface gradation was used. The results of earlier tests are believed to indicate that the gradations were too insensitive to compaction pressure and asphalt content in the ranges used. This made it impossible to obtain the desired comparisons between laboratories and the more-sensitive surface gradation was included.

Comparisons are made by presenting average test values in tabular form, by graphical illustrations, and by statistical evaluation of the data. A calibration of the kneading compactor in your laboratory as it was when this cooperative work was done is included and conclusions and recommendations, based on our interpretation of the results, are presented as a closure to the paper.

Since this cooperative work was performed, your compactor has been modified by the addition of a check valve and another compaction spring is in the machine. As a result of these changes, we were asked to recalibrate the compactor. The results of the final calibration performed on March 21, 1961 by Mr. Fred Moavenzadeh of our staff are appended to this report. Figure 7 of the Appendix shows the latest form of the load cell as used in the March 21 calibration.

We will be pleased to answer any questions that you may have regarding the contents of this report.

Very truly yours,

W. H. Goetz

W. H. Goetz
Research Engineer

WHG:kr

PURDUE TEST RESULTS

Complete test results of bulk density and Hveem stability, performed in the Joint Highway Research Project Bituminous Laboratory, are reported in this section for an Indiana AH type B surface mix. The materials (type and source) used to compose the mixture are presented in Table 1. The aggregate gradation is presented in Table 2 and shown graphically in Figure 1.

The aggregate gradation was chosen to closely approximate an AH type B mix gradation which Indiana has used. The particular gradation used here is known to coincide with the gradation used in the surface course of a 1954 project on U. S. 41 in Hammond, Indiana. This project extends approximately 1.3 miles south on U. S. 41 beginning at the U. S. 12 (Indianapolis Boulevard) intersection.

The U. S. 41 gradation was composed entirely of crushed limestone aggregate with 7.0 per cent asphalt by weight of total mix which made it a very sensitive mix. This difference in aggregate type between the U. S. 41 mixture and the mixture used for this study implies that duplicate test results would not be expected. However, the object, for this study, was to use a gradation that would be sufficiently sensitive to changes in asphalt content and kneading compaction pressure, and the U. S. 41 gradation was found to be satisfactory even after making changes in the materials in order to utilize readily available materials on hand in the laboratory.

The results of bulk density and Hveem stability tests on specimens prepared following two compaction procedures are listed in Table 3. The group A data are for specimens compacted with a semi-compaction pressure of 250 psi and a final compaction pressure of 500 psi. Group B data are for

Table 1

MIX MATERIALS

Material	Type and Source
Coarse Aggregate	Crushed limestone from the Ohio and Indiana Stone Company, Greencastle, Indiana
Fine Aggregate	Natural sand from the Western Indiana Sand and Gravel Company, Lafayette, Indiana
Asphalt	AP-5 from Texaco, Inc., Port Neches, Texas

Table 2

AGGREGATE GRADATION

FOR

INDIANA AH TYPE B SURFACE MIX

Sieve Size Passing	Sieve Size Retained	Specification Limits, % Min.	Specification Limits, % Max.	Gradation Used Percent
1/2 in.	3/8 in.	2	14	11
3/8 in.	No. 4	20	50	37
No. 4	No. 6	0	11	9
No. 6	No. 8	0	11	4
No. 8	No. 16	5	20	11
No. 16	No. 50	10	25	16
No. 50	No. 100	2	17	5
No. 100	No. 200	1	5	3
No. 200	---	3	5	4

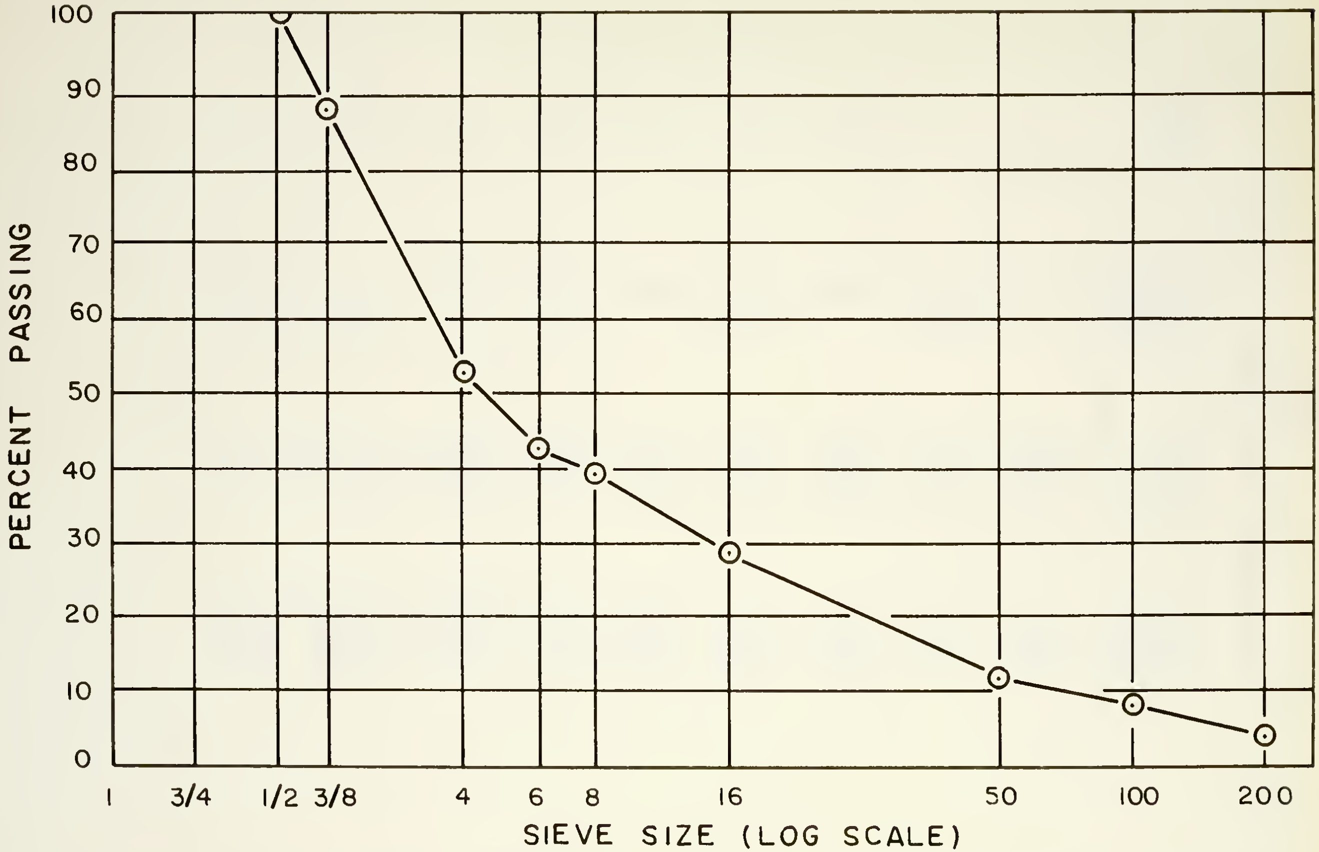


FIG. 1 AGGREGATE GRADATION CURVE FOR INDIANA AH TYPE B SURFACE MIX

Table 3

DENSITY AND HVEEM STABILITY TEST RESULTS

*Group	Percent Asphalt by Mix Wt.	Hveem Stability	Bulk Density, Pcf
A	3	40.3	142.8
A	3	40.8	142.5
A	3	43.8	143.6
A	3.5	35.9	143.0
A	3.5	38.3	145.8
A	3.5	41.0	146.3
A	4	37.8	146.5
A	4	42.4	146.7
A	4	37.8	148.0
A	4.5	40.4	147.2
A	4.5	40.6	148.0
A	4.5	38.0	148.9
A	5	35.5	148.5
A	5	40.4	147.3
A	5	41.1	149.0
A	5.5	35.9	150.6
A	5.5	37.8	150.2
A	5.5	38.2	150.2
A	6	35.9	150.9
A	6	36.2	150.8
A	6	34.9	150.8
A	6.5	5.6	150.1
A	6.5	5.7	149.9
A	6.5	12.8	149.6
A	7.0	0.6	149.3
A	7.0	1.8	149.8
A	7.0	0.6	149.3

Table 3 (cont'd)

DENSITY AND HVEEM STABILITY TEST RESULTS

*Group	Percent Asphalt by Mix Wt.	Hveem Stability	Bulk Density, Pcf
B	4.5	40.2	148.3
B	4.5	41.9	148.9
B	4.5	45.3	148.7
B	5	40.0	149.7
B	5	36.5	149.6
B	5	38.5	149.6
B	5.5	31.3	151.5
B	5.5	26.9	151.5
B	5.5	29.7	151.0
B	6	15.3	151.3
B	6	--	---
B	6	17.9	151.3
B	6.5	3.8	150.4
B	6.5	2.9	150.4
B	6.5	2.8	150.5

* Group A: 14.5 psi gage pressure, 250 psi semi-compaction pressure; 32 psi gage pressure, 500 psi final compaction pressure.

Group B: 16.5 psi gage pressure, 275 psi semi-compaction pressure; 39 psi gage pressure, 600 psi final compaction pressure.

specimens compacted at 275 psi semi-compaction pressure and 600 psi final compaction pressure.

Average values of these data are tabulated in Table 4 of a following section and several figures are also presented there to illustrate the data trends.

PROCEDURE VARIATIONS

Several variations in the sample preparation, compaction, and testing procedures exist between the Indiana State Highway Department (ISHD) and the Joint Highway Research Project (Purdue) bituminous laboratories. Some variation is to be expected, especially since the Purdue laboratory is set up for small-scale research testing and the ISHD laboratory is set up for large-scale routine testing. It would be extremely tedious, and possibly without final conclusion, to attempt to evaluate the effect of each difference. Therefore, it is thought that opinion based on experience will be satisfactory for assessing the effects of procedure variations in this study. The most apparent procedure variations are recorded below and it is suggested that they be kept in mind when comparing test results between the two laboratories.

1. Although the same type of mixer is used in each laboratory, the bowls and mixing paddles are different. Purdue uses a flat-bottom bowl and flat mixer paddle with a knife-like scraper which rotates about the inner circumference of the mixing bowl. The ISHD uses the rounded-bottom bowl furnished by the mixer manufacturer and a wire mixing paddle also supplied by the manufacturer. Purdue uses a two-minute mixing period for all mixes. The ISHD has no set time for mixing. Generally, they mix until the mixture appears to have a uniform distribution of bitumen.

2. It is believed that the compaction temperature of mixes in the ISHD laboratory are lower than in the Purdue laboratory. This would probably have some significant effect on final density and, therefore, on the Hveem stability of a sensitive mixture. The ISHD uses ovens which are set for the desired temperature (230°F for compaction) and it is found that approximately 1 1/2 hours are required to heat a sample to the compaction temperature. The

Purdue ovens are set considerably higher than the desired temperatures and a period of less than 30 minutes is normally sufficient to heat the sample to 15°F in excess of the prescribed compaction temperature. The excess 15°F allows for cooling while placing the mix in the mold.

3. The ISHD uses the standard insulated trough when placing a mix in the compaction mold. However, they arbitrarily place an excess of fine mix at either end of the trough to obtain smoother top and bottom faces on the compacted specimen. Supposedly this procedure provides for smooth faces on the specimen and results in more uniform contact pressure during the Stabilometer test. They also apply the required number of rod tamps to the bottom layer of mix in the mold, but only 1/2 the required number of tamps are applied to the top layer. The top layer tamps are applied only around the mold edge. Purdue does not use the insulated trough but prefers the excess 15°F temperature procedure which allows for rodding the material in the mold on a nearby hard-surface table and avoids any interference with the compactor foot. The tamping rod used by Purdue is 1/2 inch in diameter (3/8 inch is standard) and it does not have a bullet-nosed end. The reason for using this modified rod is that it was available at the time when one was needed and no attempt has been made to replace it with a standard rod.

Other procedure variations have also been noticed. Purdue uses the standard 11 x 7 x 1 1/2 inch curing pans and the ISHD does not. The 140°F ovens in each laboratory differ. The Purdue oven has horizontal shelves for convenient placing of extruded specimens prior to testing. The ISHD oven does not have shelves of this type and specimens sometime become distorted prior to testing. Accommodations may have been made to modify this before the writing of this report.

COMPARISON OF TEST RESULTS

A discussion and comparison of the test results obtained in the ISHD and Purdue laboratories are presented in this section. Average values have been determined from the original data and these averages are reported in Table 4. The data of Table 4 have been used to draw the five figures of this section (Figures 2 through 6).

There are three groups of data, as shown in Table 4. The basis of separation of the groups is the compaction pressure applied, and these pressures are recorded as footnotes to Table 4.

In the A and B groups the ISHD tested specimens only in the critical asphalt content range which had been determined by the Purdue work. In either group the critical range was from 5 to 6.5 per cent of asphalt when one-half per cent increments were used. In addition, the ISHD performed a similar series of tests using their standard compaction procedure. This series is labeled group C.

Figures 2 and 3 show bulk density and Hveem stability curves for the average data of groups A and B, respectively. These figures show clearly that the ISHD density values are generally about 1 pcf above the Purdue values and that this density variation results in lower stability values in the ISHD laboratory. With this information available it appears probable that if the density results were to coincide between laboratories, the Hveem stability values would also agree. This is understandable, and to be expected, as long as the two compaction devices impart the same type of loading action. With these facts as evidence, it seems that specimen density may have been a better basis of comparison between results of the two laboratories, rather than the peak compaction pressure.

Table 4

SUMMARY OF TEST RESULTS

Group	Asphalt Content by Mix Wt, %	Hveem Stability		Bulk Density, pcf		Aggregate Density, pcf	
		ISHD	Purdue	ISHD	Purdue	ISHD	Purdue
A (a)	3	---	42	---	143.0	---	138.7
A	3.5	---	38	---	145.0	---	139.9
A	4	---	39	---	147.1	---	141.2
A	4.5	---	40	---	148.0	---	141.3
A	5	37	39	150.2	148.3	142.7	140.9
A	5.5	32	37	151.5	150.3	143.2	142.0
A	6	31	36	151.6	150.8	142.5	141.8
A	6.5	8	8	151.8	149.9	141.9	140.2
A	7	---	1	---	149.5	---	139.0
B (b)	4.5	---	43	---	148.6	---	141.9
B	5	34	38	151.1	149.6	143.5	142.1
B	5.5	27	29	151.4	151.3	143.1	143.0
B	6	10 (d)	17 (d)	152.0(d)	151.3(d)	142.9	142.2
B	6.5	4	3	151.1	150.9	141.3	141.1
C (c)	5	33	---	151.0	---	143.5	---
C	5.5	25	---	151.0	---	142.7	---
C	6	17 (d)	---	151.0(d)	---	141.9	---
C	6.5	5	---	151.1	---	141.3	---

(a) All group A data are for a semi-compaction pressure of 250 psi and final compaction pressure of 500 psi.

(b) All group B data are for a semi-compaction pressure of 275 psi and final compaction pressure of 600 psi.

(c) All group C data are for a semi-compaction pressure of 330 psi and a final compaction pressure of 660 psi.

(d) These values are an average of two test results. All other values reported are an average of three test results.

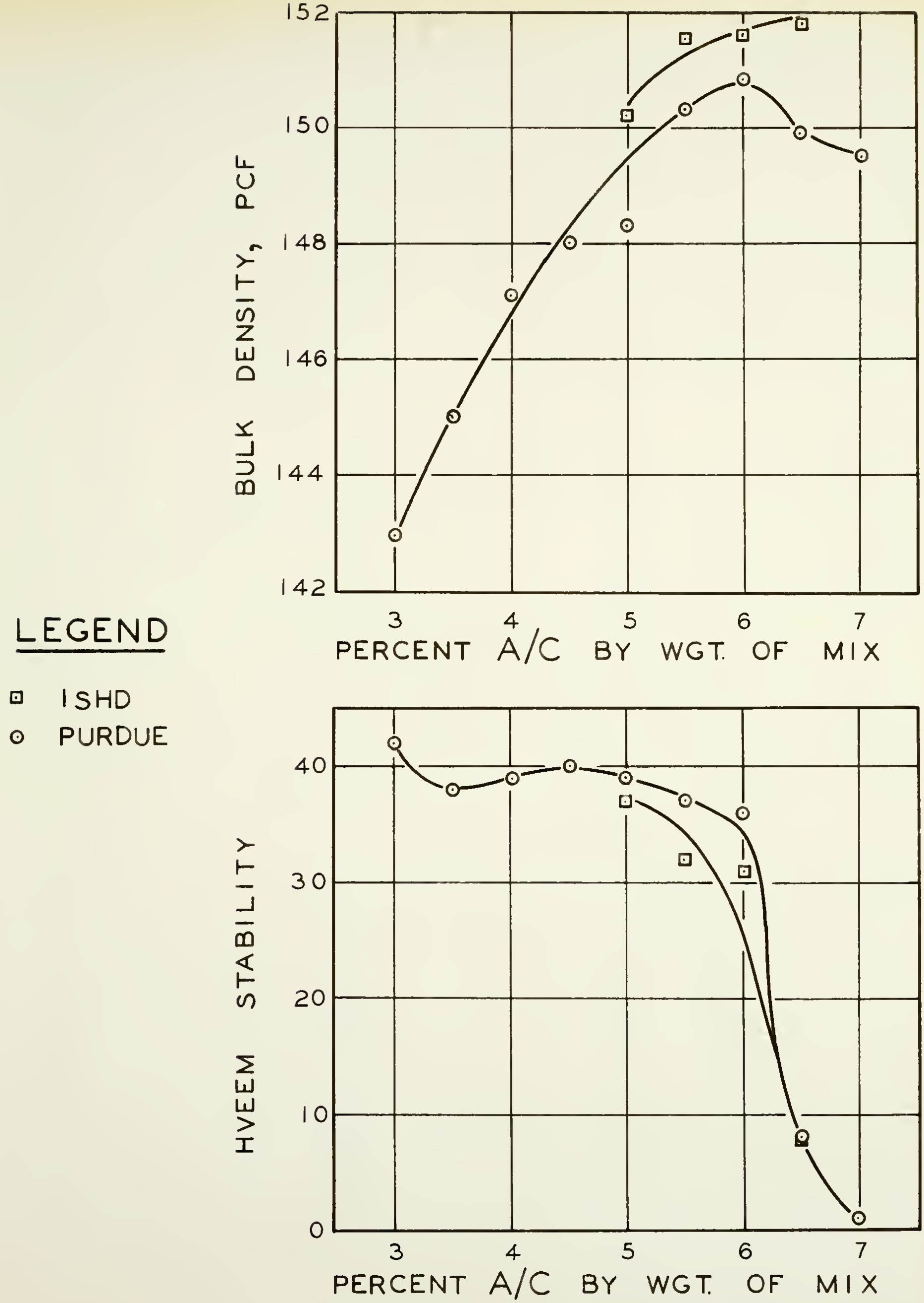


FIG. 2 CURVES FOR GROUP A DATA

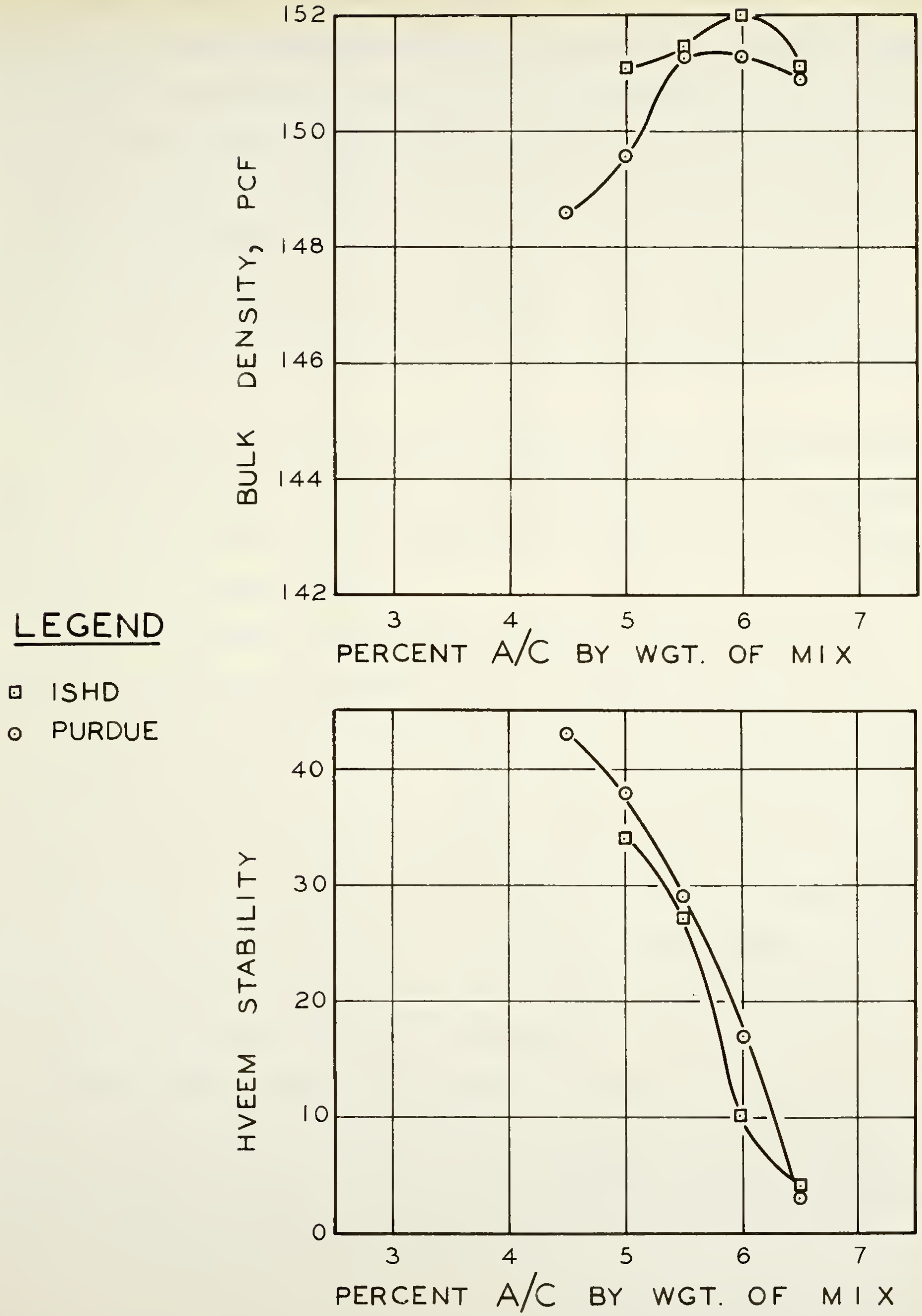


FIG. 3 CURVES FOR GROUP B DATA

Another significant feature of Figures 2 and 3 is that with an increase of 100 psi in the peak compaction pressure for group B, as compared to Group A, the density does not change markedly and the peak (maximum density) remains at about 6 per cent asphalt content. However, the Hveem stability values do change considerably with this change in compaction pressure, the decrease in stability with increase in asphalt content being more uniform at the higher compaction pressure (group B - Figure 3). For either the group A or group B data the Hveem stability at 6.5 per cent asphalt content is less than 10.

Figure 2 shows an increase in Hveem stability when the asphalt content is decreased from 3.5 to 3 per cent. This illustrates that the Stabilometer primarily measures the internal friction of the aggregate and not the cohesive properties of the asphalt binder.

All values in Table 4 are plotted in Figure 4, 5 and 6. The same comments generally apply to Figures 4 and 5 as stated for Figures 2 and 3. The group C data obtained by the ISHD using their standard compaction procedure are included in Figures 4, 5 and 6. With the high compaction pressure of 660 psi for group C, the bulk density did not vary over a range of asphalt contents from 5 to 6.5 per cent. This is shown in Figure 5. However, the Hveem stability values range from 35 to 5 for these same specimens. The importance of simulating the true pavement condition when using average density values is emphasized by this information.

Figure 4 shows extremely low stability for specimens containing 6.5 per cent or more asphalt for any of the five compaction procedures given. The more gradual decrease in stability with increases in asphalt content at the higher compaction pressures is also shown.

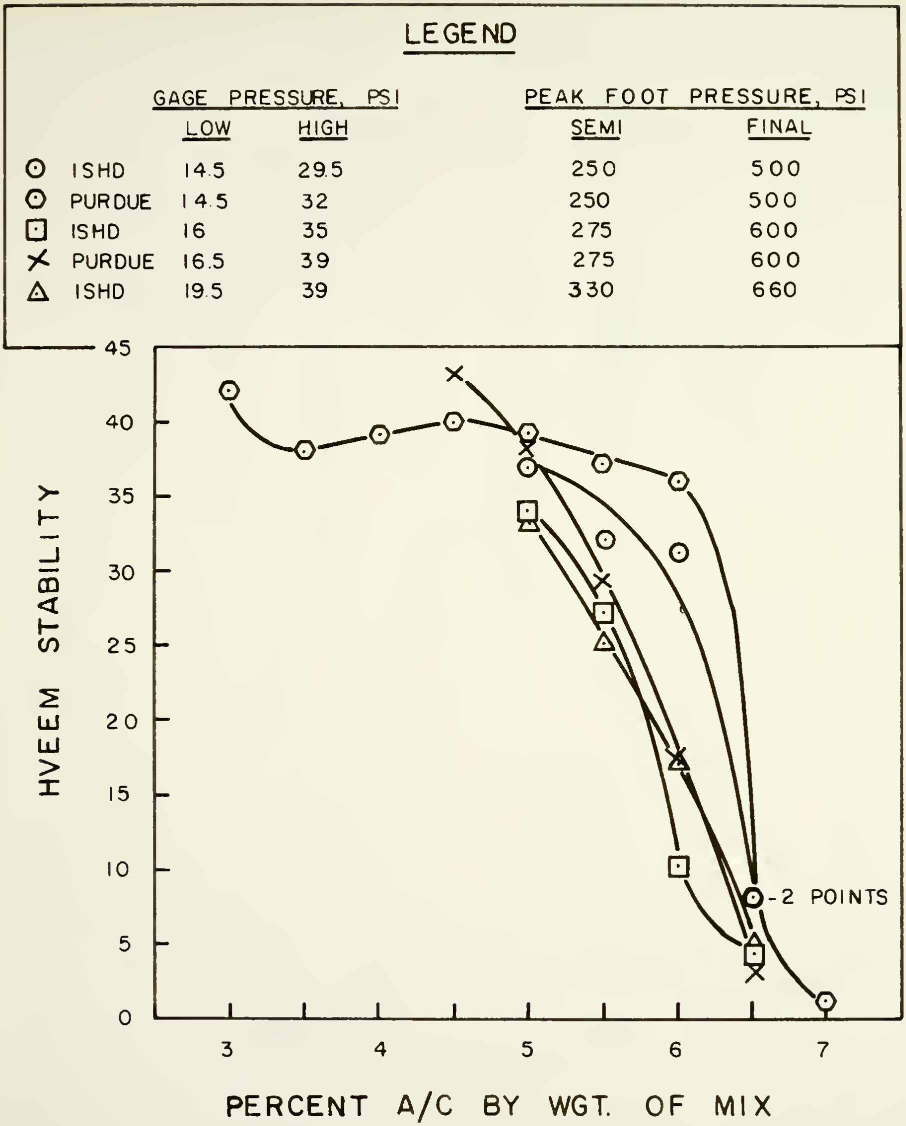


FIG. 4 VARIATION OF HVEEM STABILITY WITH A/C AND COMPACTION PRESSURE

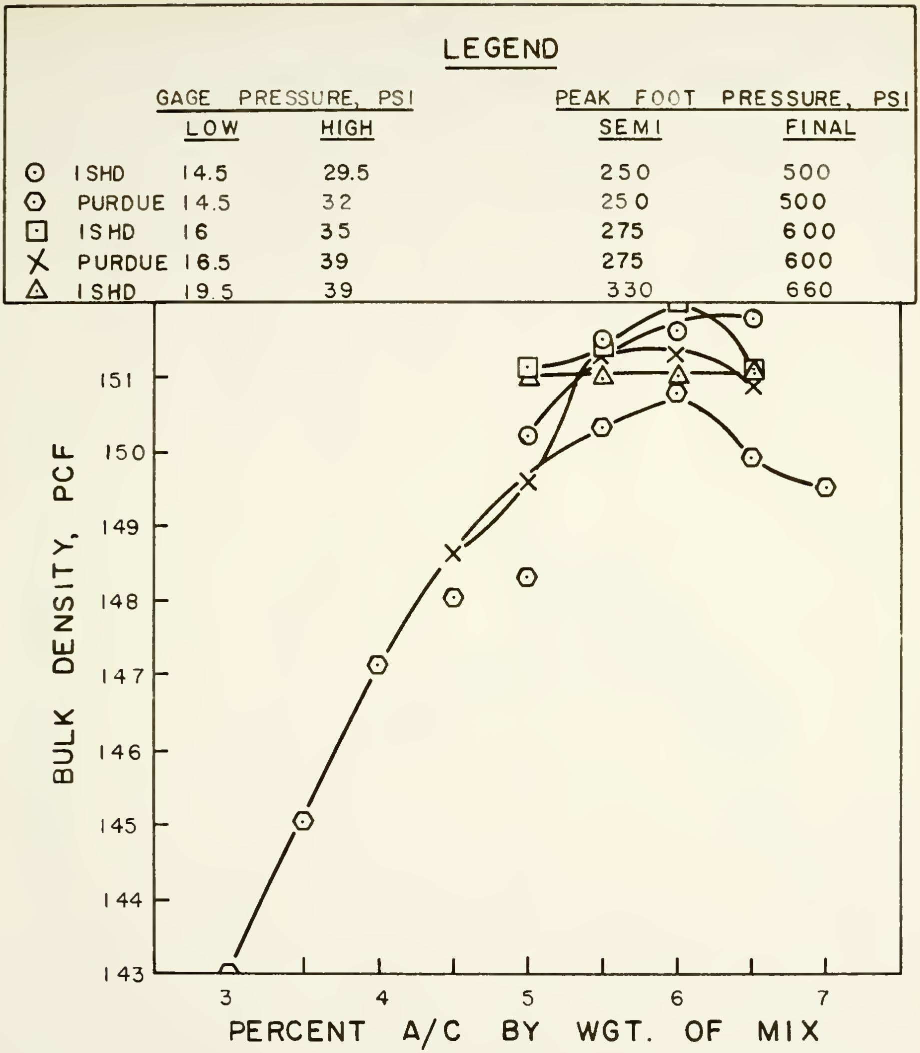


FIG. 5 VARIATION OF BULK DENSITY WITH A/C AND COMPACTION PRESSURE

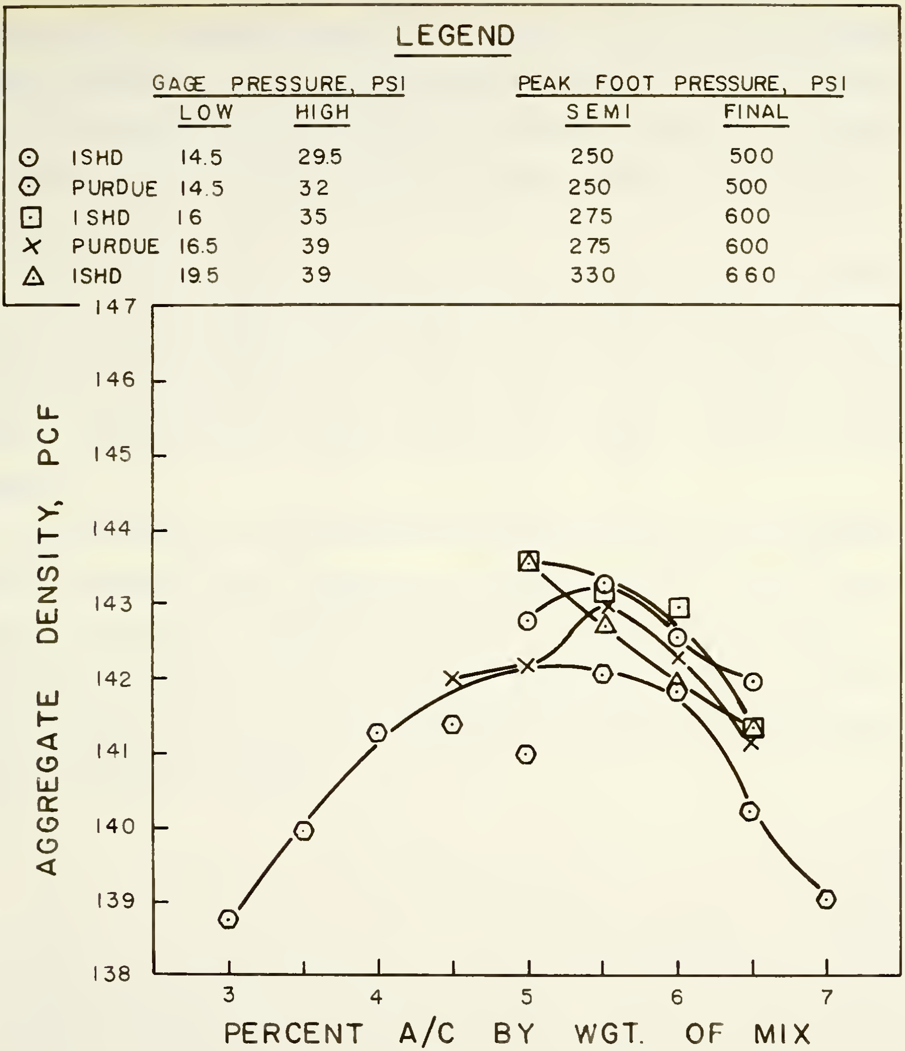


FIG. 6 VARIATION OF AGGREGATE DENSITY WITH A/C AND COMPACTION PRESSURE

Figure 5 shows a peak density around 6 per cent asphalt content for a considerable variation in peak foot pressure. A study of several comparable points of Figures 4 and 5 will show the wide variation of Hveem stabilities that can be obtained with relatively small changes in bulk density. This is especially true for the right side of the density curves, after the peak density is obtained.

Figure 6 shows a peak aggregate density at about 5.5 per cent asphalt when the standard 500 psi compaction pressure is used. Increases in compaction pressure, accordingly, decrease the asphalt content at which maximum density occurs. Generally, Hveem stability appears to be closely related to aggregate density.

On the basis of the data presented and discussed here it is suggested that the gradation studied should have an asphalt content of near 5.5 per cent by mix weight for optimum performance. Using this asphalt content, standard compaction (500 psi) would give an aggregate density of 142.5 pcf, a bulk density of 151 pcf, a Hveem stability of 35 and an air void content of approximately 2 per cent.

STATISTICAL EVALUATION OF DATA

The purpose of this section is to evaluate several of the test results obtained in both laboratories on a statistical basis. The evaluation consists of three major determinations:

1. Using individual test results, ranges of test results are computed; an allowable range is also computed for each laboratory.

2. Comparisons of the test results for bulk density and Hveem stability are made between laboratories by the method of differences.

3. Comparisons by the method of differences of the test results for bulk density and Hveem stability are made for the ISHD data using 500 psi compaction and the compaction pressure they have used to date (660 psi).

Range Tests (1)

Table 5 presents the range computations for bulk density and Hveem stability for the comparative work done between laboratories with the group A and group B mixtures. Allowable range limits are also given in Table 5.

It is readily seen that density and stability ranges for each laboratory are well within the allowable limits for that laboratory. This is true, also, when the limiting values of the ISHD data are checked against the actual values obtained in the Purdue laboratory. There is at least one ISHD result outside the Purdue limiting values for each set of data, except for the group A densities. The most significant feature of Table 5 is probably the fact that higher range values are obtained by the ISHD, especially for the Hveem stability values.

Table 6 is included only for supplementary information. It was thought desirable to have information concerning the possible bulk density and Hveem

Table 5

Range Values for Groups A and B Data (a)
(Comparison of ISHD and Purdue Values)

Group	A/C	(Range of Three)			
		Bulk Density, pcf		Hveem Stability	
		ISHD	Purdue	ISHD	Purdue
A	5	0.8	1.7	6	6
A	5.5	1.7	0.4	14	2
A	6	0.7	0.1	6	1
A	6.5	0.0	0.5	6	7
Sum		3.2	2.7	32	16
$\bar{R}$*		0.8	0.7	8	4
$D_3\bar{R}$ - $D_4\bar{R}$**		0 - 2.1	0 - 1.8	0 - 21	0 - 10
B	5	2.3	0.1	8	4
B	5.5	0.6	0.5	7	4
B	6	0.4	0	13	3
B	6.5	0.4	0.1	2	1
Sum		3.7	0.7	30	12
$\bar{R}$*		0.9	0.2	7.5	3
$D_3\bar{R}$ - $D_4\bar{R}$**		0 - 2.3	0 - 0.5	0 - 19	0 - 8

(a) Refer to reference (1) for table of D_3 and D_4 values.

* Average Range. ** Allowable Range.

Table 6

Supplementary Range Values (a)

A. Purdue Laboratory - Groups A and B Data

A/C	(Range of Three)			
	Bulk Density, pcf		Hveem Stability	
	Grp A	Grp B	Grp A	Grp B
3	1.3		3.5	
3.5	3.3		5.1	
4	1.5		4.6	
4.5	1.7	0.6	2.6	5.1
5	1.7	0.1	5.6	3.5
5.5	0.4	0.5	2.3	4.4
6	0.1	0.1	1.3	2.6
6.5	0.5	0.0	7.2	1.0
7	0.5		1.2	
Sum	11.0	1.3	33.4	16.6
$\bar{R}$*	1.2	0.3	3.7	3.3
$D_3\bar{R}$ - $D_4\bar{R}$**	0 - 3.1	0 - 0.8	0 - 9.5	0 - 8.5

B. ISHD Laboratory - Cohesiometer Data

	(Range of Three) Cohesiometer Values		
A/C	Group A	Group B	Group C
5	44	41	63
5.5	100	31	34
6	46	21	96
6.5	64	50	69
Sum	254	143	262
$\bar{R}$*	64	36	66
$D_3\bar{R}$ - $D_4\bar{R}$**	0 - 165	0 - 93	0 - 170

C. ISHD Laboratory - Group C Data

Group	A/C	(Range of Three)	
		Bulk Density, pcf	Hveem Stability
C	4.5	1.0	1
C	5	0.2	4
C	5.5	0.7	14
C	6	1.1	4
Sum		3.0	23
$\bar{R}$*		0.8	6
$D_3\bar{R}$ - $D_4\bar{R}$**		0 - 2.1	0 - 15.5

(a) Refer to reference (1) for table of D_3 and D_4 values.

* Average Range. ** Allowable Range.

stability limits that can ordinarily be expected for duplicate specimens. For this reason, complete data were used for both group A and group B tests in the Purdue laboratory. These data are sufficient for a rather "strong" test, especially in the case of group A. The results show that at standard compaction (500 psi - group A) a range in density of approximately 3 pcf and a range in stability of approximately 9.5 should be considered as maximum values.

Cohesiometer range values determined from the ISHD data are well within the range limitations as can be seen in Table 6. Also, in Table 6, the group C density and stability range values based on the ISHD data are acceptable. However, the wide range in permissible Hveem stability values is again indicated.

Comparisons of ISHD and Purdue Data by Method of Differences

Table 7 presents the computations for determining if the differences in bulk density and Hveem stability values between the two laboratories are statistically significant. The table is presented in four parts (A, B, C and D) since four comparisons are made between the groups A and B data of the ISHD and Purdue laboratories.

Acceptance or rejection of the test hypothesis is reported at a significance level of .05 for each test. This level is generally thought to be standard for accepting or rejecting a hypothesis using data obtained by routine laboratory methods.

For a .05 significance level, parts A and B of Table 7 show that the group A Hveem stability values obtained in the two laboratories are not significantly different but the density values are significantly different. Neither stability nor density are significantly different for group B, as

Table 7

COMPARISONS OF ISHD AND PURDUE DATA (a)

For all tests assume: 1) matched-pair samples
2) normal populations

Hypothesis: The average of the results obtained by the Purdue laboratory is equal to that obtained by the ISHD laboratory.

Significance level: .05

A. Hveem Stability - Group A

A/C	Hveem Stability		D	D^2		
	ISHD	Purdue				
5	38	36	-2	4	$\bar{d}$	= 3.33
5	39	40	1	1		
5	33	41	8	64	s_d^2	= 31.5
5.5	39	36	-3	9	s_d	= 5.62
5.5	32	38	6	36		
5.5	25	38	13	169	t	$= \frac{3.33}{5.62}\sqrt{12}$
6	32	36	4	16		
6	33	36	3	9		
6	27	35	8	64		= 2.06
6.5	5	6	1	1	$t_{11,\ .05}$	= 2.20
6.5	7	6	-1	1		
6.5	11	13	2	4		
			40	378		

Conclusion: Accept the hypothesis at a significance level of .05.

(a) Refer to reference (2) for test details of the method of differences.

(continued)

Table 7 (continued)

COMPARISONS OF ISHD AND PURDUE DATA (a)

Bulk Density - Group A.

A/C	Bulk Density, pcf		D	D^2		
	ISHD	Purdue				
5	149.8	148.5	1.3	1.69	$\bar{d}$	= 1.46
5	150.1	147.3	2.8	7.85		
5	150.6	149.0	1.6	2.56	$s_{\bar{d}}^2$	= 2.69
5.5	150.6	150.6	0	0	s_d	= 1.64
5.5	152.3	150.2	2.1	4.41		
5.5	151.7	150.2	1.5	2.25	t	$= \frac{1.46}{1.64}\sqrt{12}$
6	151.3	150.9	0.4	0.16		
6	151.6	150.8	0.8	0.64		
6	152.0	150.8	1.2	1.44		= 3.09
6.5	151.8	150.1	1.7	2.89	$t_{11,\ .05}$	= 2.20
6.5	151.8	149.9	1.9	3.61		
6.5	151.8	149.6	2.2	4.84		
			17.5	32.34		

Conclusion: Reject the hypothesis at a significance level of .05.

(a) Refer to reference (2) for test details of the method of differences.

(continued)

Table 7 (continued)

Comparisons of ISHD and Purdue Data (a)

C. Hveem Stability Group B.

A/C	Hveem Stability		D	D^2		
	ISHD	Purdue				
5	39	40	1	1	$\bar{d}$	= 1.82
5	31	37	6	36		
5	33	39	6	36	s_d^2	= 24.0
5.5	27	31	4	16	s_d	= 4.90
5.5	30	27	-3	9		
5.5	23	30	7	49	t	$= \frac{1.82}{4.90}\sqrt{11}$
6	22	15	-7	49		
6	9	-	--	--		
6	10	1[illegible]	8	64		= 1.23
6.5	4	4	0	0	$t_{10, .05}$	= 2.23
6.5	3	3	0	0		
6.5	5	3	-2	4		
			20	264		

Conclusion: Accept the hypothesis at a significance level of .05.

(a) Refer to reference (2) for test details of the method of differences.

(continued)

Table 7 (continued)

COMPARISONS OF ISHD AND PURDUE DATA (a)

D. <u>Bulk Density - Group B</u>

A/C	Bulk Density, pcf		D	D^2		
	ISHD	Purdue				
5	149.7	149.7	0	0	$\bar{d}$	= 0.67
5	152.0	149.6	2.4	5.76		
5	151.5	149.6	1.9	3.61	s_d^2	= 1.06
5.5	151.7	151.5	0.2	0.04	s_d	= 1.03
5.5	151.1	151.5	-0.4	0.16		
5.5	151.3	151.0	0.3	0.09	t	$= \frac{0.67}{1.03}\sqrt{11}$
6	151.6	151.3	0.3	0.09		
6	152.0	----	----	----		
6	152.0	151.3	0.7	0.49		= 2.16
6.5	150.9	150.4	0.5	0.25	$t_{10,\ .05}$	= ± 2.23
6.5	151.1	150.4	0.7	0.49		
6.5	151.3	150.5	0.8	0.64		
			7.4	11.62		

Conclusion: Accept the hypothesis at a significance level of .05.

(a) Refer to reference (2) for test details of the method of differences.

shown by parts C and D of Table 7. Results appear to be more uniform between laboratories for the higher compaction pressure of group B than for the standard compaction pressure of group A.

With respect to the standard compaction pressure, parts A and B of Table 7 show that an average difference of about 3 in Hveem stability is not significant, and an average difference of about 1.5 pcf in density is significant. Comparing the actual "t" values calculated with those at the .05 significance level, it appears that values for duplicate specimens prepared and tested in different laboratories should, on the average, not differ by more than about 4 in Hveem stability or more than about 1 pcf in bulk density.

Comparisons of ISHD Groups A and C Data by Method of Differences

Computations for statistical comparisons of the ISHD groups A and C data appear in Table 8. The group C data were obtained by the compaction procedure which has been used since the kneading compactor was installed for operation (330 psi semi-compaction pressure and 660 psi final compaction pressure). The group A data were obtained using the standard compaction pressures (250 psi semi-compaction pressure and 500 psi final compaction pressure).

Part A of Table 8 shows that the mean of the Hveem stability values obtained by the two procedures are significantly different. Previous calculations using Purdue data have shown that a range of about 9 is the maximum allowable variation between duplicate specimens tested in the same laboratory. The average difference (range) between the matched samples in part A of Table 8 is 7.9 and values range from 1 to 23.

Table 8

Comparisons of ISHD Groups A and C Data (a)

For all tests assume: 1) matched-pair samples
2) normal populations

Hypothesis: The mean for group A is equal to the mean for group C.

Significance level: .05

A. Hveem Stability

A/C	Hveem Stability Grp A (500 psi)	Hveem Stability Grp C (660 psi)	D	D^2	
5	38	33	5	25	$\bar{d} = 7.9$
5	39	33	6	36	
5	33	32	1	1	$s_d^2 = 117.3$
5.5	39	23	16	256	$s_d = 10.8$
5.5	32	25	7	49	
5.5	25	27	-2	4	$t = \frac{7.9}{10.8}\sqrt{12}$
6	32	18	14	196	$= 2.54$
6	33	16	17	289	
6	27	4	23	529	$t_{11,.05} = 2.20$
6.5	5	3	2	4	
6.5	7	5	2	4	
6.5	11	7	4	16	
			95	1409	

Conclusion: Reject the hypothesis at a significance level of .05.

(a) Refer to reference (2) for test details of the method of difference.

(continued)

Table 8, continued

Comparisons of ISHD Groups A and C Data (a)

B. Bulk Density

A/C	Bulk Density, pcf		D	D^2	
	Grp A (500 psi)	Grp C (660 psi)			
5	149.8	150.6	-0.8	0.64	$\bar{d} = 0.258$
5	150.1	150.8	-0.7	0.49	
5	150.6	151.6	-1.0	1.00	$S_d^2 = 0.683$
5.5	150.6	151.0	-0.4	0.16	$S_d = 0.83$
5.5	152.3	150.9	1.4	1.96	
5.5	151.7	151.1	0.6	0.36	$t = \frac{0.258}{0.83}\sqrt{12}$
6	151.3	150.6	0.7	0.49	
6	151.6	151.3	0.3	0.09	$= 0.108$
6	152.0	151.0	1.0	1.00	
6.5	151.8	150.7	1.1	1.21	$t_{11,.05} = 2.20$
6.5	151.8	150.9	0.9	0.81	
6.5	151.8	151.8	0	0	
			3.1	8.21	

Conclusion: Accept the hypothesis.

(a) Refer to reference (2) for test details of the method of differences.

Part B of Table 8 shows that the density results obtained by the two compaction procedures are not significantly different. Again, the possible large effect on Hveem stability of a small density change is indicated by these results.

It is concluded that for mixtures closely approximating the one used for this study, specimen densities obtained using the present ISHD compaction procedure are probably satisfactory but Hveem stability values are generally somewhat lower than for standard compaction. This means that the past results will contain an added factor of safety. The effect of this compaction pressure variation on other common Indiana mixtures is not known, but generally gradations will not be more sensitive than the one used in this investigation and the differences in density and stability would be expected to be less significant.

CALIBRATION OF ISHD KNEADING COMPACTOR

A calibration of the ISHD kneading compactor has been made and the results are reported in this section. Previous work done in the Purdue laboratory has shown that the procedure used is reliable for obtaining peak foot pressures produced by a given air pressure (gage pressure).

Figure 7 pictures the equipment used in the calibration operation. Figure 8 gives details of the load cell and electrical connections.

Four series of pressure-time traces were obtained and the peak pressures were averaged to obtain a final calibration curve. Each series of traces was for a different arrangement of the load cell in order to balance possible errors in the recorded traces due to unsymmetric loading of the cell. Figure 9 shows a typical series of traces with the average peak foot pressure recorded above each trace for the four arrangements of the load cell. The bypass valve was open 1-3/4 turns for all readings for two reasons: 1) the pressure-time traces obtained are similar to the traces obtained with the Purdue kneading compactor (bypass valve also open 1-3/4 turns), and these traces are about what is desired by the California standards; and 2) this is the opening which the ISHD had been using prior to the calibration of the machine and it was thought that maintaining the same bypass valve setting would allow more meaningful comparisons to be made between data previously obtained and data obtained by a change in compaction pressure.

Figure 10 is the final calibration curve for the kneading compactor. The curve shows that the machine should be operated with air pressures (gage pressures) of 14.5 psi and 29.5 psi to obtain peak foot pressures of 250 psi and 500 psi, respectively. 250 psi and 500 psi are the standard

KEY

1. AMPLIFIER WITH CALIBRATION SET FOR 15 MM. DIVISIONS OFFSET. OPERATE WITH ATTENTUATOR FACTOR SETTING OF 5 WHEN CALIBRATING.
2. CAPACITOR WITH SETTING OF 0.01 MICROFARAD.
3. OSCILLOGRAPH RECORDER. OPERATE AT 25 MM. PER SECOND FOR DESIRED TRACE.

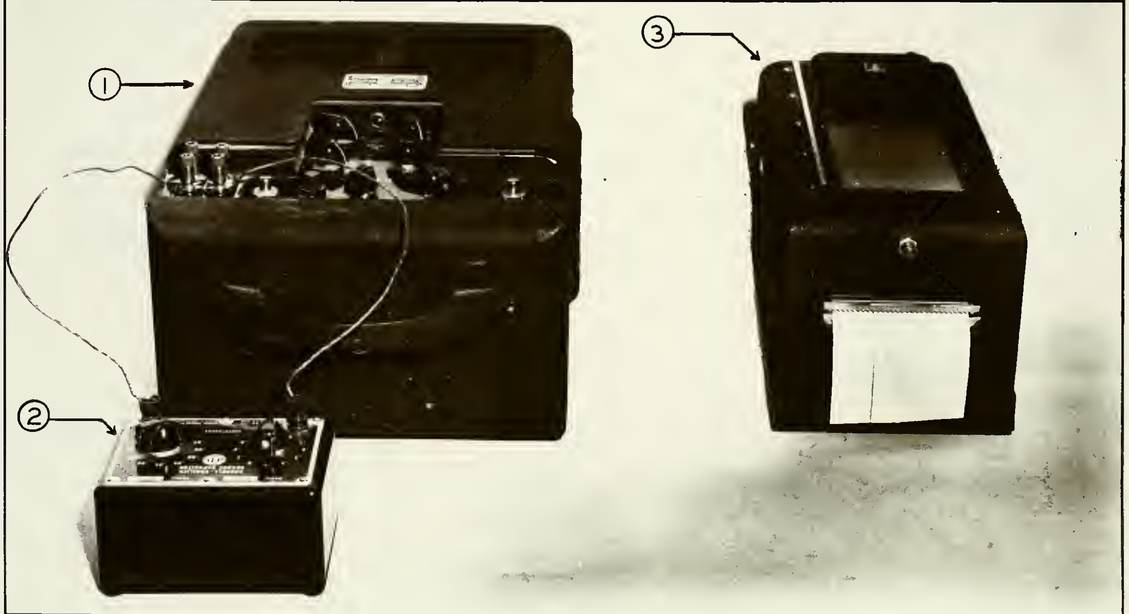


FIG. 7 INSTRUMENTS FOR CALIBRATING THE KNEADING COMPACTOR

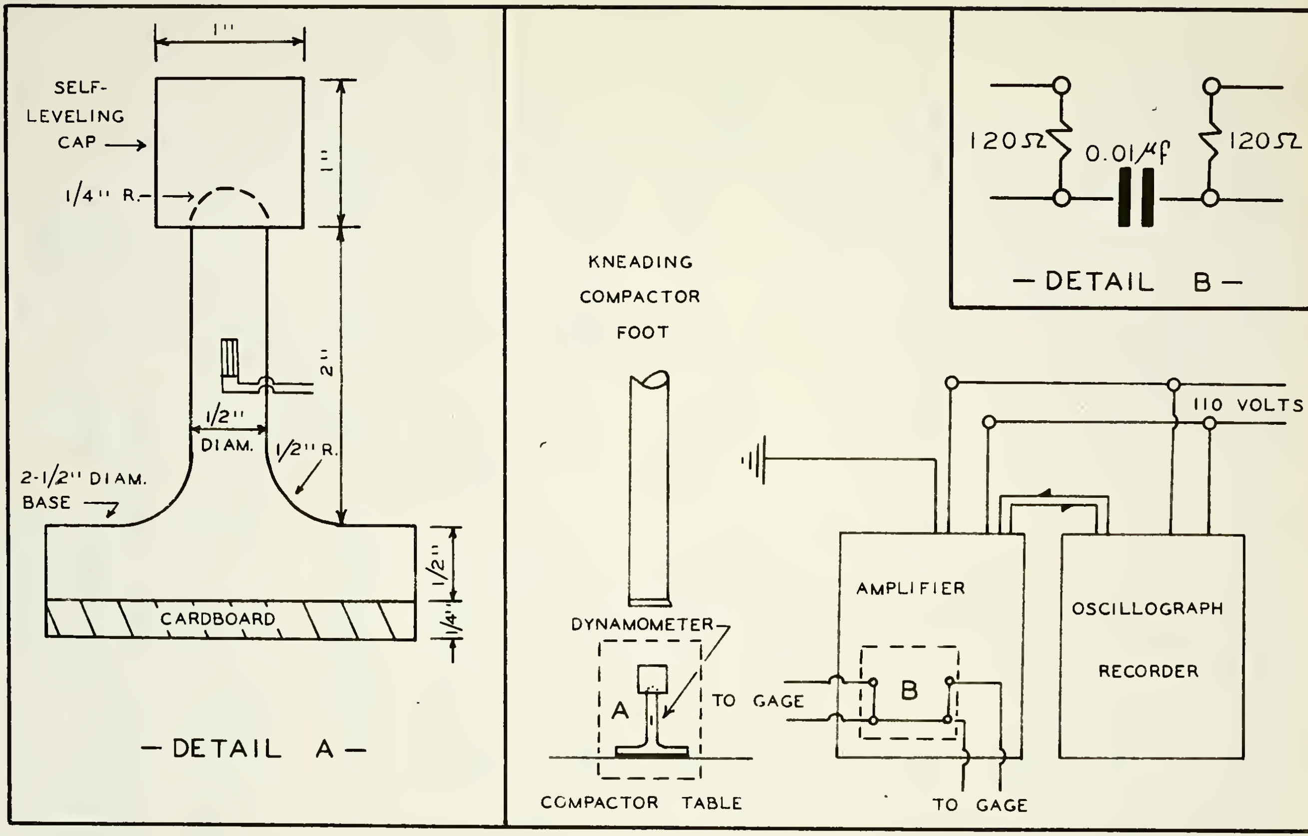


FIG. 8 DIAGRAM OF CALIBRATION EQUIPMENT

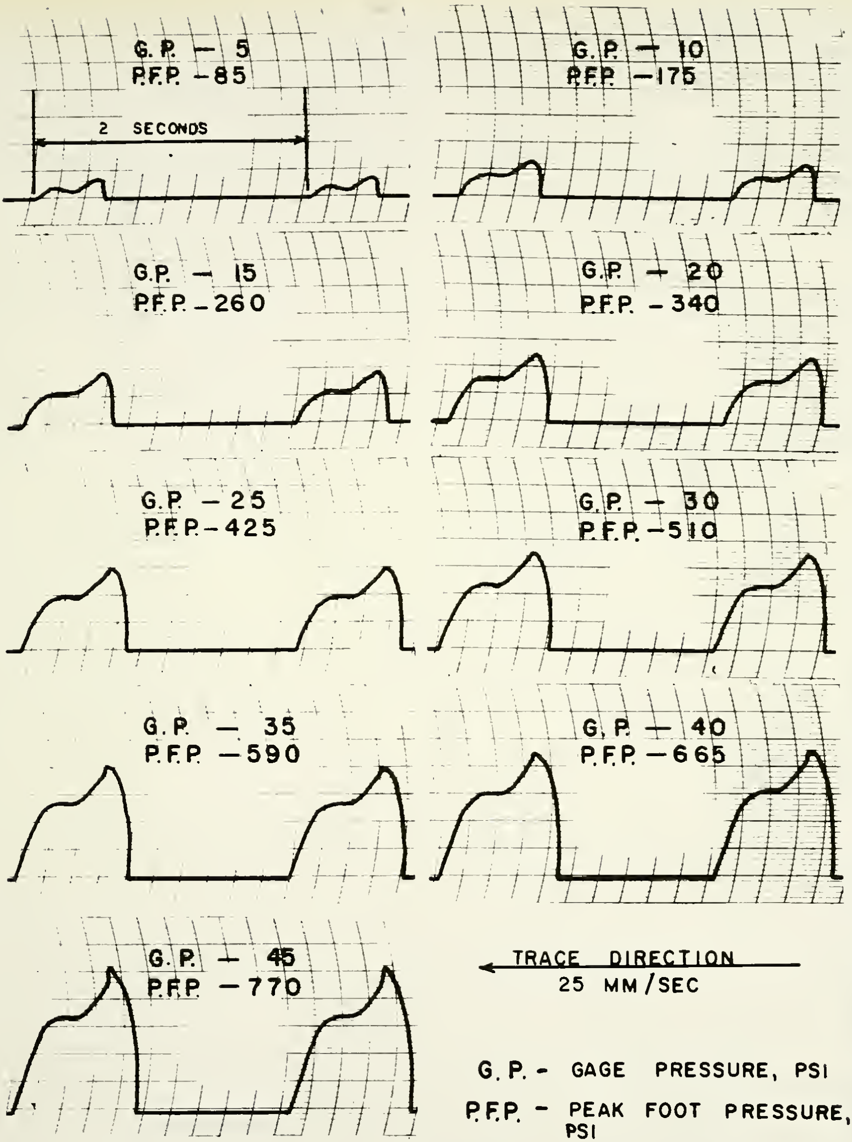


FIG. 9 TYPICAL SERIES OF PRESSURE-TIME TRACES - BYPASS VALVE OPEN 1- 3/4 TURNS

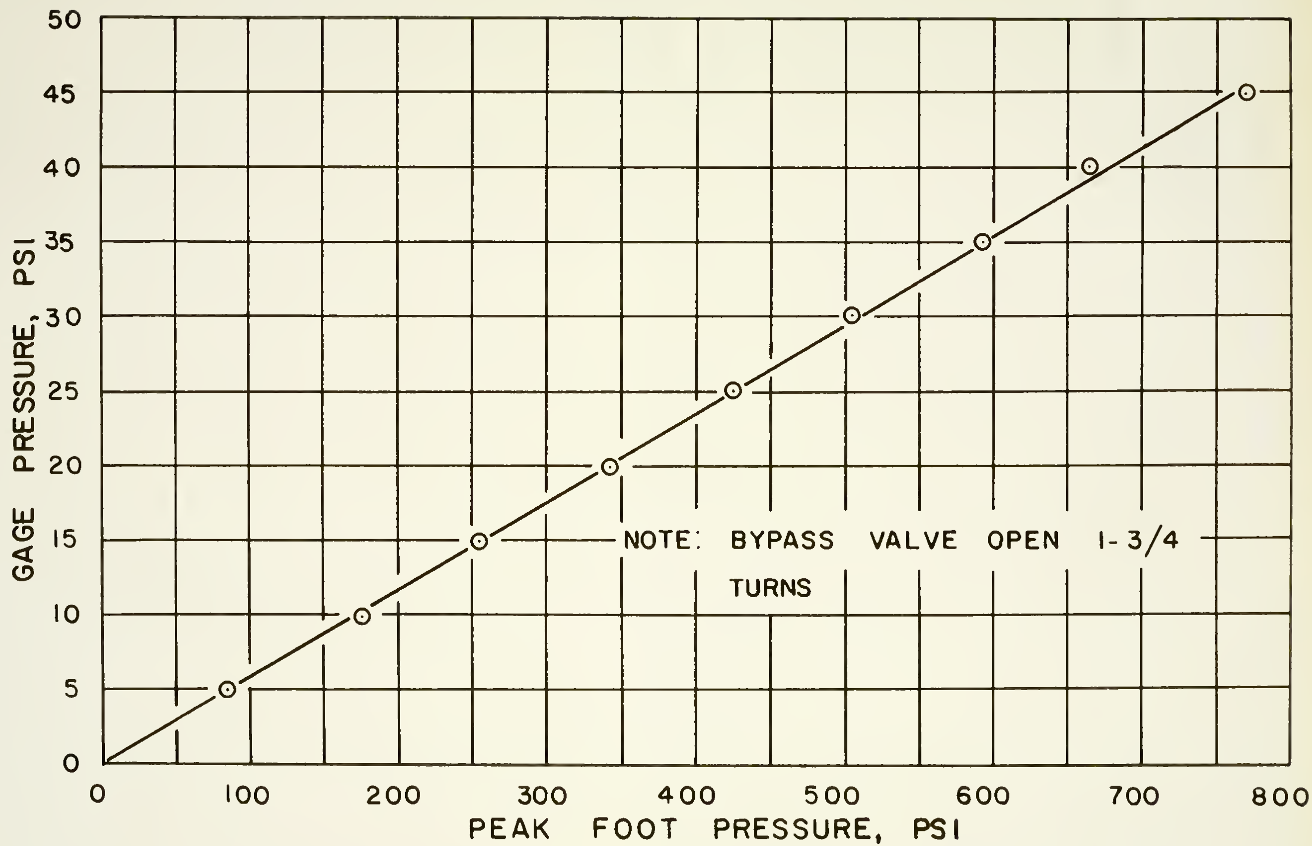


FIG. 10 CALIBRATION CURVE FOR KNEADING COMPACTOR

compaction pressures. It is important that the bypass valve be set to 1-3/4 turns open if the proper pressures are to be applied using the above gage pressures.

The calibration curve shows that a semi-compaction pressure and final compaction pressure of 330 psi and 660 psi, respectively, resulted with the gage pressures of 19.5 psi and 39 psi that have been used since the machine was installed. These gage pressures were taken from a calibration curve supplied by the manufacturer. However, the calibration obtained from the manufacturer was with a low-capacity spring in the tamper leg of the kneading compactor. The spring which the ISHD has been using has a higher capacity, as the straight-line calibration curve indicates. Therefore, given gage pressures will not yield the same peak foot pressures for the two springs and, because of the different spring constants, the load cycles will not have the same loading and unloading times even when peak foot pressures are made comparable.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the findings of this study several conclusions and recommendations are summarized in this section. The procedure variations between the ISHD and Purdue laboratories should not be overlooked, and it is also important to state that these final statements result from the work done using a single gradation, which is shown to be very sensitive to changes in asphalt content and compaction pressure. The conclusions and recommendations are listed below:

1. Generally, trends indicated by the ISHD and Purdue data are similar. The information available indicates that if the density results were to coincide between laboratories, the Hveem stability values would also agree. This implies that the average specimen density is probably a more fundamental basis than the peak foot pressure for comparing laboratory compaction. Of course, this statement is assumed to be correct only if the two types of compaction being compared are very similar, as in the case of this study.

2. Increases in compaction pressure appear to result in more uniform specimen density since the stability drop is more gradual with asphalt content increases. Evidence is given that very small changes in average specimen density may result in high Hveem stability changes, especially for more sensitive mixtures.

3. The results of this study show that an asphalt content of 5.5 per cent by weight of mix will result in the most satisfactory overall properties for the surface gradation studied.

4. On the basis of statistical evaluation of the test data, it is shown within this report that the ISHD consistently obtains a wide range of Hveem stability results for duplicate specimens. Oftentimes, the Hveem

stability range of a series of tests was found to exceed the maximum allowable range of about 9 established using Purdue data and standard compaction pressures. Therefore, it is recommended that attempts be made to improve on the uniformity of Hveem stability values in the ISHD laboratory. This may well mean giving some consideration to the procedure variations presented in this report. It should be pointed out that statistical calculations show there is no significant difference between Hveem stability values obtained in the two laboratories but the density values were significantly different when standard compaction pressures were used. Calculations are included in the report to establish maximum differences in duplicate samples of about 1 pcf for density and about 4 for Hveem stability when the specimens are prepared and tested in separate laboratories using standard compaction pressures.

5. The compaction pressures used by the ISHD to date are shown by the kneading compactor calibration, included in this report, to be a 330 psi semi-compaction pressure and a 660 psi final compaction pressure. It is concluded that the use of these compaction pressures has resulted in density values which are comparable with those obtained using standard compaction. However, Hveem stability results are generally somewhat lower for the high pressures and this adds a factor of safety to designs based on the high-pressure compaction procedure. Differences in density and Hveem stability using the two compaction procedures would be expected to be less significant for less sensitive gradations than the one used in this work.

6. A calibration curve for the ISHD kneading compactor is included in this report. Following this calibration it is recommended that for future work a bypass valve opening of 1-3/4 turns be used and that air pressures of 14.5 psi and 29.5 psi be used to obtain the standard 250 psi and 500 psi, semi and final compaction foot pressures, respectively.

REFERENCES CITED

1. Burr, I. W., Engineering Statistics and Quality Control, p. 409, New York, McGraw-Hill Book Company, Inc., 1953.

2. Bennett, C. A., and Franklin, N. L., Statistical Analysis in Chemistry and the Chemical Industry, p. 180f, New York, John Wiley and Sons, Inc., 1954.

Appendix I

March 21, 1961

Calibration of ISHD

Kneading Compactor

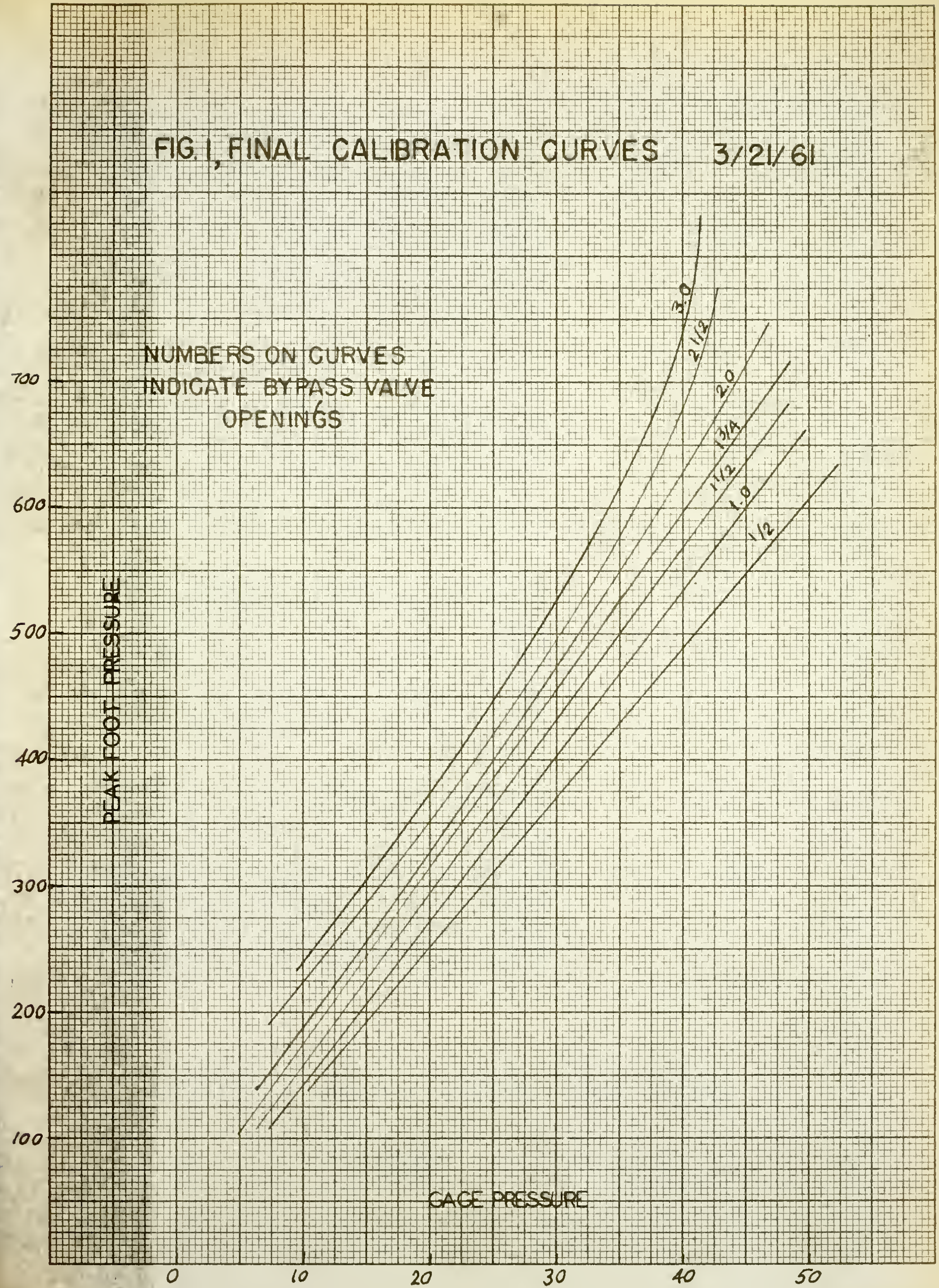
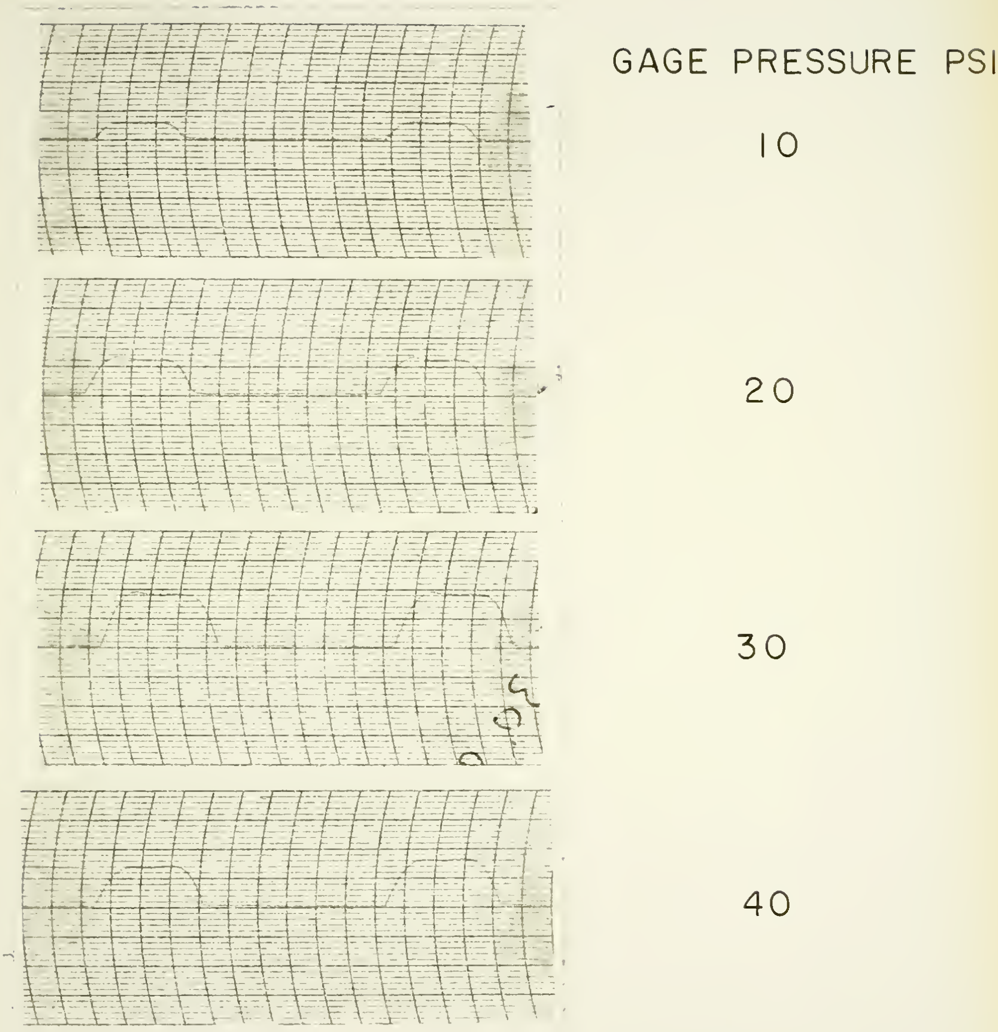
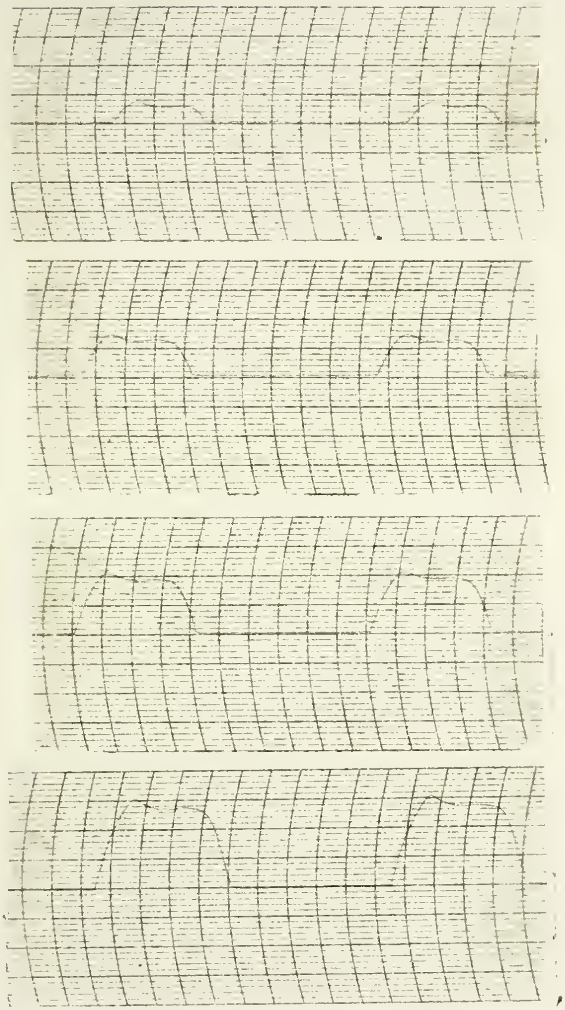


FIG. 1, FINAL CALIBRATION CURVES 3/21/61
NUMBERS ON CURVES
INDICATE BYPASS VALVE
OPENINGS
3.0
2 1/2
2.0
1 3/4
1 1/2
1.0
1/2
PEAK FOOT PRESSURE
700
600
500
400
300
200
100
GAGE PRESSURE
0
10
20
30
40
50



BYPASS VALVE OPEN 1/2 TURN

FIG.2



GAGE PRESSURE PSI

10

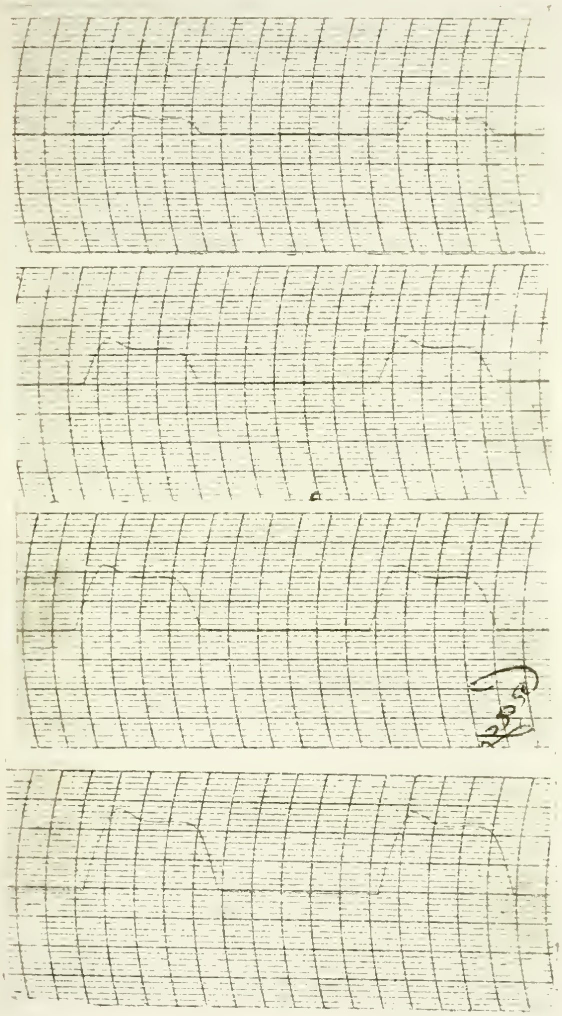
20

30

45

BYPASS VALVE OPEN 1.0 TURN

FIG. 3



GAGE PRESSURE PSI

10

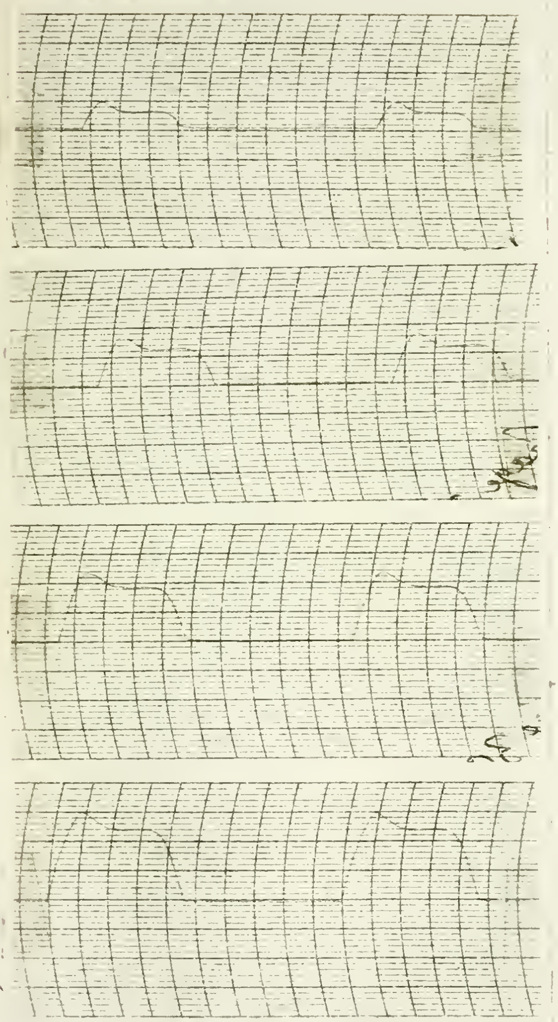
20

30

40

BYPASS VALVE OPEN 1 1/2 TURN

FIG. 4



GAGE PRESSURE PSI

10

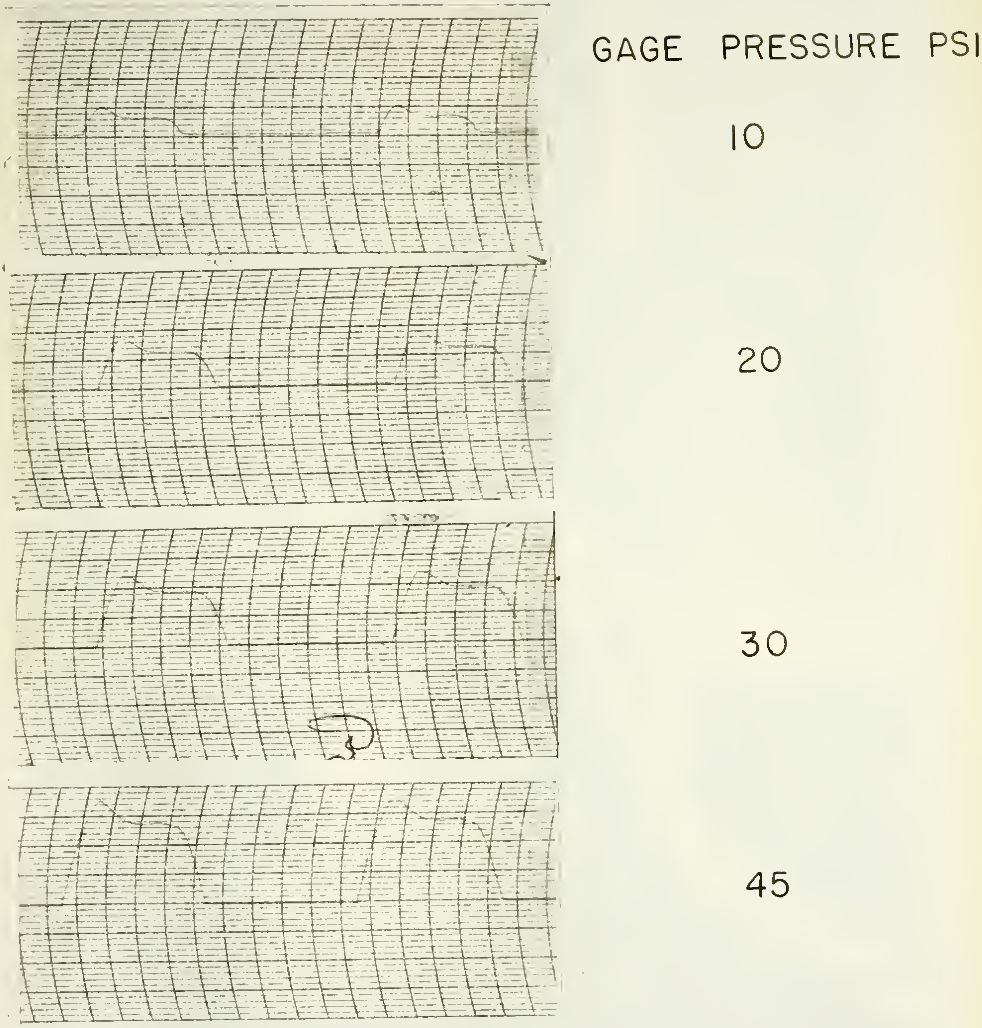
20

30

40

BYPASS VALVE OPEN 1 3/4 TURN

FIG. 5



BYPASS VALVE OPEN 2.0 TURN

FIG. 6

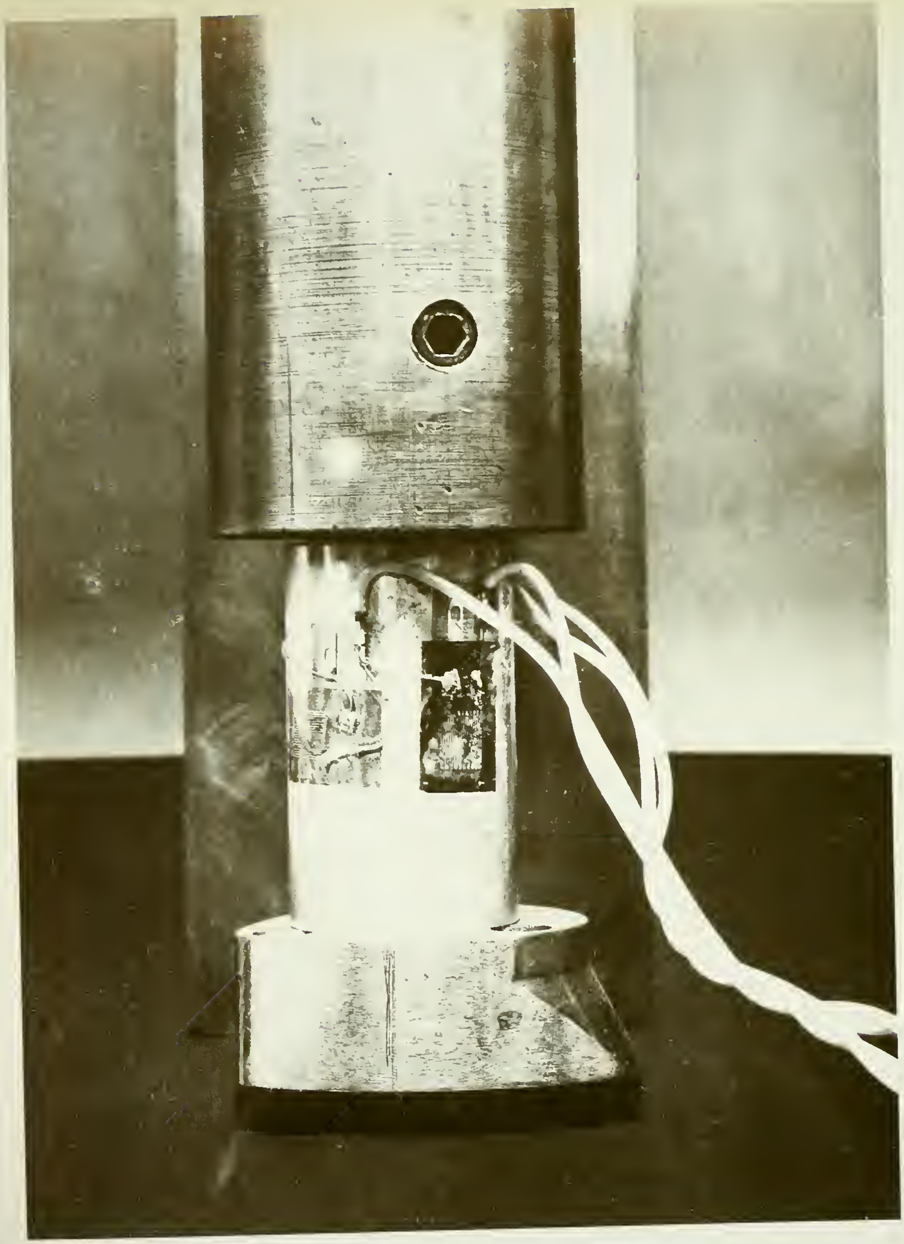


FIG. 7